DUST INSECTICIDES FOR THE CONTROL OF THE IMPORTED CABBAGE WORM

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THE CONNECTICUT AGRICULTURAL
EXPERIMENT STATION
NEW HAVEN, CONNECTICUT

Bulletin 590

March, 1955

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INTRODUCTION

The imported cabbage worm is the larva of the common white cabbage butterfly, (*Pieris rapae* [L.]), and feeds on the leaves of cabbage, cauliflowers and other members of the family *Cruciferae.* Since 1944, the imported cabbage worm has been controlled successfully by use of DDT dusts and sprays. Reports were received, however, from growers in Connecticut during 1953 that the pest had become difficult to deal with by this means. An experiment was, therefore, carried out during 1954 at the Mount Carmel Farm of this Station to see if an increase in resistance to DDT, such as that described by McEwen and Chapman (6) and by Hervey and Swenson (5), could be demonstrated and if any of the newer insecticides would be likely to prove satisfactory alternatives.

It is not yet possible to predict the time required for an insect population to manifest increased tolerance to an insecticide. This depends on the interaction of many factors, some as yet little understood; the type of insecticide, the mechanism of tolerance or resistance, the efficiency of the control measure or pressure of selection, the rate of reproduction, and the migrational and other habits of the insect may all be expected to influence the situation. However, it is now quite apparent that, in certain cases, only a relatively short period of time has been required for the imported cabbage worm to become highly resistant to applications of DDT. For instance, in the Kenosha and Racine areas of Wisconsin only some 15 generations of the pest (taking about five years) were needed before a change of control measure became necessary. If the insect were to behave similarly towards other insecticides, a change of control measure might be necessary at least every five years, which is almost less time than that taken to develop a new poison. Thus, in order to keep the pest in check, the present wasteful periodic search for alternative pesticides must continue indefinitely unless a solution to the problem is forthcoming.

At the present time, there appear to be two main approaches by means of which it may be possible to prevent appreciable tolerance changes occurring. Both methods involve a new outlook on the efficient use of insecticidal materials. In the first instance it may be possible to provide at least a temporary answer to the problem by using a ro-

[1]With notes on the life cycle and habits in Connecticut.
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tation of insecticides with each one having a different mode of toxic action against the pest and no one material being used too frequently. For this approach, it is obvious that a sufficient number of suitable toxicants must be available to allow for the organization of the rotation. The success of this method would depend to a large extent on the acquired resistance being "diluted" (genetically or otherwise) during the time lapsing between applications of each specific chemical. There is some indication that over a period of two years, since abandoning the use of DDT in Wisconsin, there has been a slight reduction in the resistance to DDT acquired by the imported cabbage worm (2).

An alternative approach to the problem is one involving the simultaneous use of two insecticides which differ in their modes of toxic action (8), i.e., the independent joint action of two poisons. The use of "combination" poisons has been more fully explored during work carried out on the resistance behavior of bacteria to antibiotics (3), a situation which may be parallel to that of insect resistance to insecticides. It is suggested that, other things being equal, the time required for a given increase in resistance to occur when two poisons are thus used may be substantially greater than the sum of the times for the two materials if used separately. The net total useful "lives" of the two chemicals would thus be considerably extended.

Insufficient experimental data are yet available to enable the entomologist to state which of these two methods of approach to the "insect resistance problem" is likely to provide the best answer. It has, however, become apparent that there is a danger that the exclusive use of one chemical may lead only to a repetition of the present *status quo* in imported cabbage worm control and that it will be necessary in future to have a series of suitable materials on which to draw. For this purpose, considerable information on the relative values of numerous insecticides is necessary. In the experiment described below, an evaluation is given of the merits of five of the newer insecticides.

TEST OF INSECTICIDES

The efficiencies of several insecticides were compared for control of the imported cabbage worm in this experiment. The experiment was arranged in a randomized block layout to give three replicates of each treatment. The cabbages (variety Danish Ballhead) were planted at intervals of two feet in rows three feet apart. Single row plots each containing 12 plants were used but assessments were made on only the center ten plants of each plot.

The materials tested were DDT, toxaphene, Dilan, dieldrin, isodrin and endrin.[1] With the exception of endrin, all were used in a series of three concentrations which were decided upon empirically and arranged to have an interval factor of x3. Unfortunately, shortage of space on the experimental area allowed for the use of only two extreme concentrations of endrin. The dusts were all prepared from commer-

[1] For chemical names see MARTIN, H. (1953). Guide to the Chemicals Used in Crop Protection, 2nd. Edition, Canada Department of Agriculture.

cial formulations by diluting with pyrophyllite (Pyrax ABB) to the required concentration. As only small amounts were needed, the mixing was done by shaking for several minutes in a two-pint container which had been fitted internally with meshes to break up the dust. This was found to produce an even, if not exactly intimate, mix.

Each dust was applied at a rate of approximately 32 lb. per acre, an amount normally considered necessary for satisfactory operation of a commercial duster, and one commonly used in practice. This rate was the equivalent of about 25 gm. per plot and necessitated the design and construction of a small hand duster capable of applying such small amounts plot by plot with an accuracy of about ± 10 per cent. With the large number of treatments involved, it was also desirable to use some form of rapidly interchangeable dust container. This enabled all the materials to be weighed out beforehand, the speed of the dusting operation was not impaired and no tiresome "cleaning out" was needed between treatments.

The type of hand duster used is shown schematically in Figure 1.

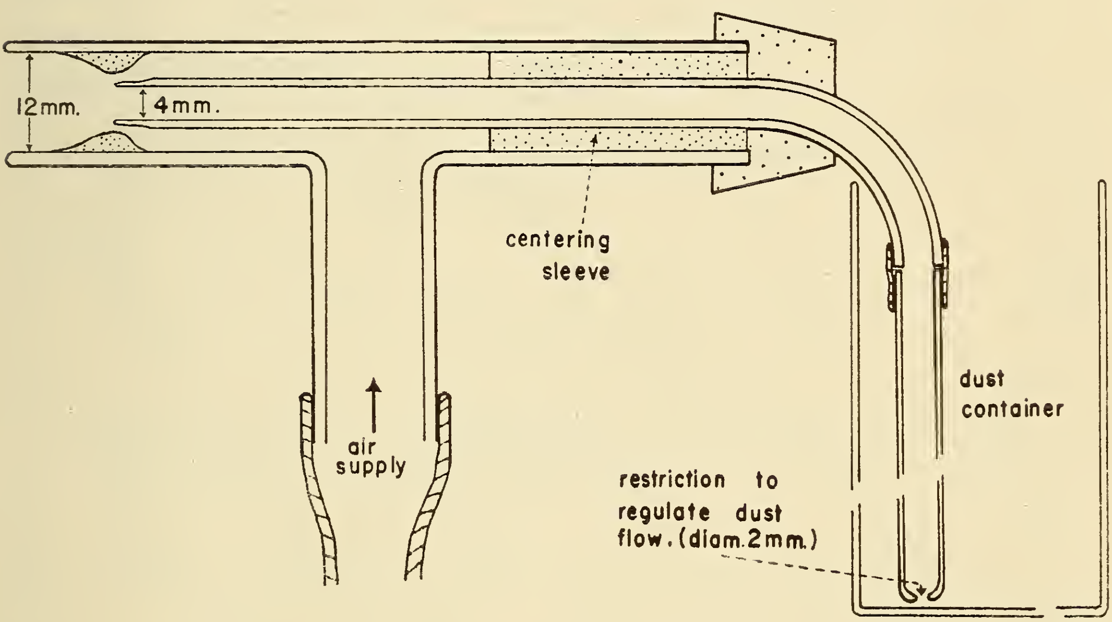

Figure 1. Diagram of hand duster. (Drawing is not made to scale.)

The principle of operation is the same as that commonly used for small spray atomizers but, of course, it was necessary to use a delivery tube of larger bore than that suitable for a liquid. In order to prevent the delivery tube from choking with dust, the flow was governed by restricting the in-put and not the out-put end as is usual for liquids. A convenient form of dust container was found to be either one- or two-pint sized "ice-cream cartons"; the dust delivery tube was held in the carton with one hand while the free hand was used to manipulate the compressed air tube. The suction normally produced by such a venturi nozzle system is quite adequate to maintain a steady flow providing that the dust in the reservoir is not allowed to "cake" or "bridge".

This was prevented by steadily shaking the dust container while dusting. The compressed air was supplied at 5 lb. per sq. in. from a portable gasoline-operated compressor.

The prevailing temperature conditions, times of treatments and the phases of the insect population present during the course of the experi-

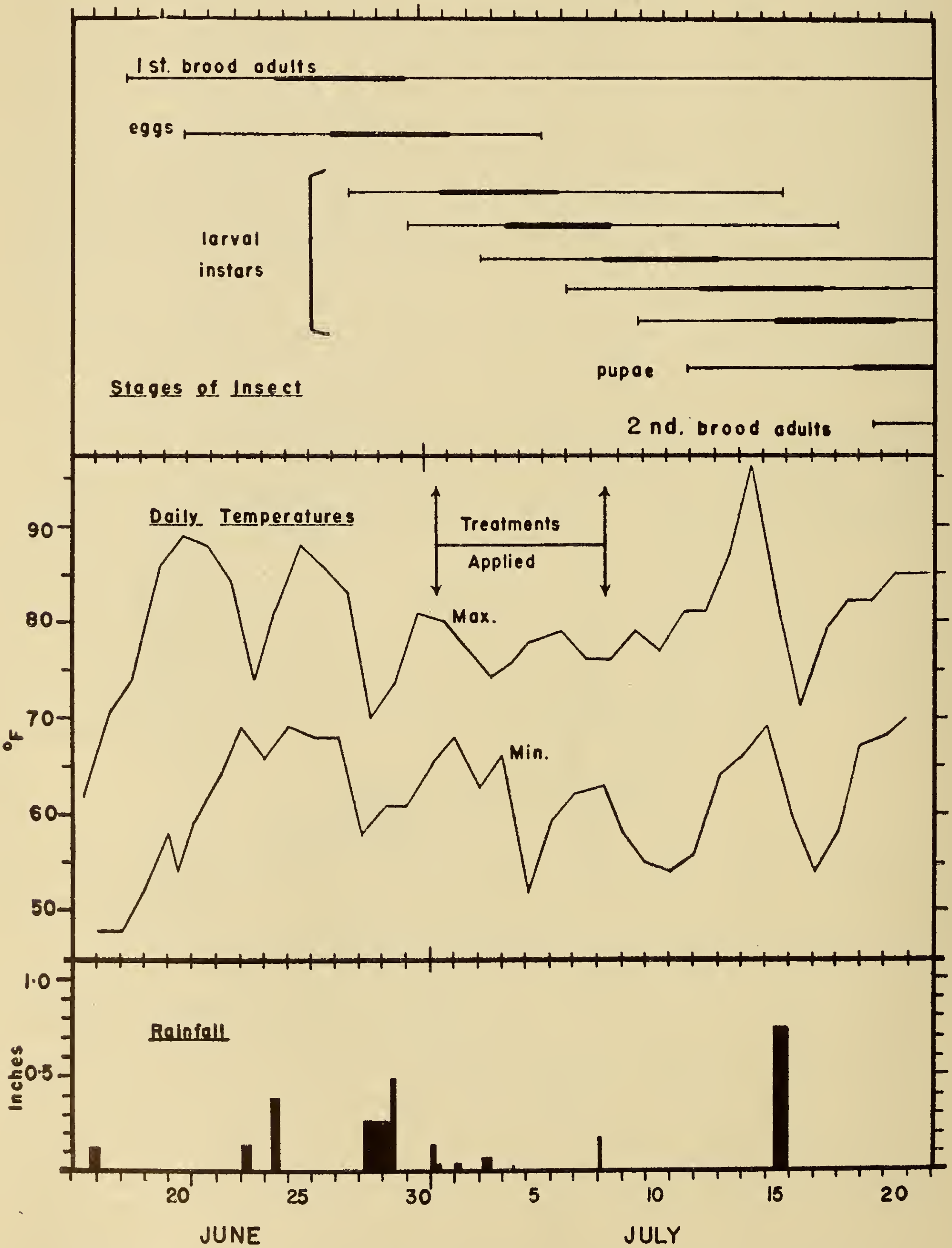

Figure 2. Conditions of experimentation: stage of the insect, daily maximum and minimum temperatures, and rainfall.

ment, are shown in Figure 2. The treatments were applied on June 30 and on July 8 and counts were made on the surviving larvae and pupae on July 12 and 13. These results are summarized in Tables 1 and 2 and have been plotted on a logarithmic-probability grid in Figure 3 to show more clearly the relative behavior of the materials against

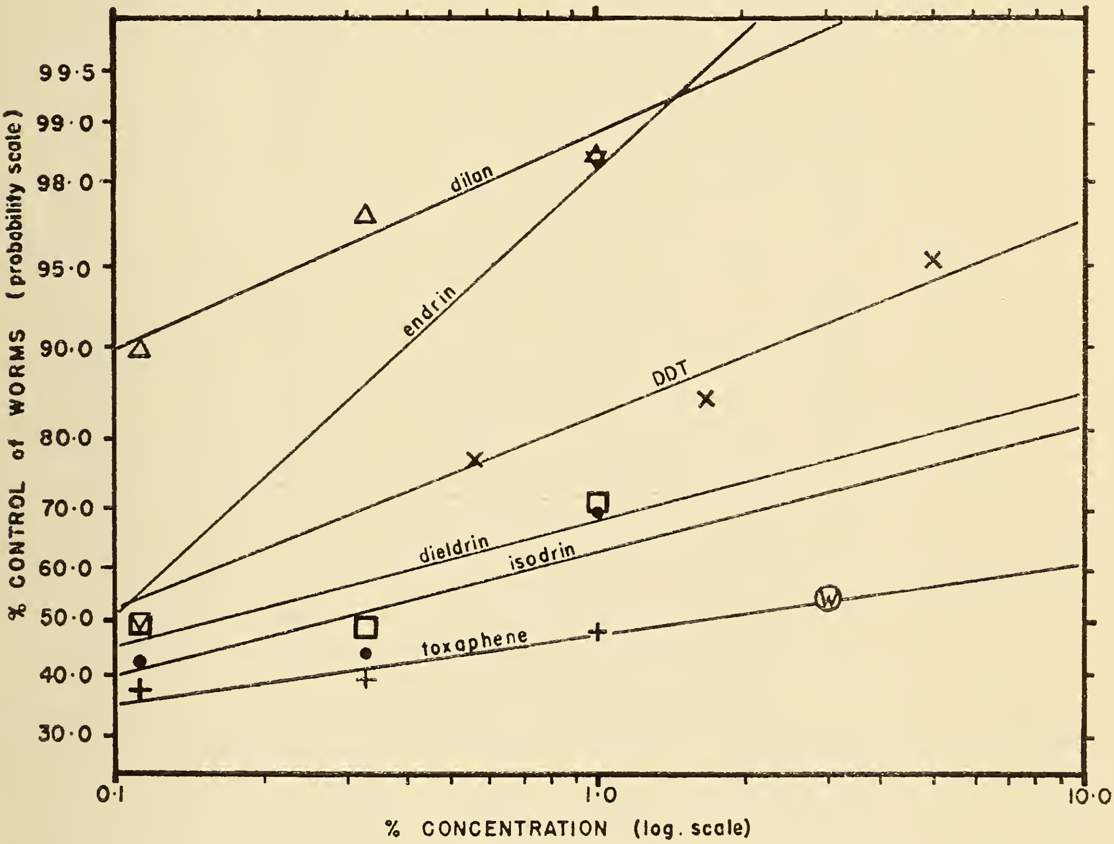

Figure 3. The effect of concentration on the performance of the insecticidal dusts against the imported cabbage worm. Regression of percentage control (on a scale of probits) as a function of the percentage concentration of toxicant (on a logarithmic scale.)

the caterpillar. Estimates of control of damage were also made on July 12 and 13 and again on July 19. Plants were graded into one of six damage categories scored 0, 1 . . . . . . 5 and these results are also given in Table 1.

The best control of the pest was obtained with Dilan and endrin, both of which gave approximately 98 per cent reduction in larval population when used at concentrations of 1 per cent. The next most effective material was DDT and an adequate (95 per cent) control resulted from the use of a 5 per cent dust. Dieldrin and isodrin did not appear to give a very satisfactory control of larvae but the amount of damage present on the plants treated with these materials was much less than the figures indicate (Table 1). It seemed that toxaphene, dieldrin and isodrin were but slowly effective, and that it was not until the larvae became larger that they acquired lethal quantities of the materials and succumbed (Table 2). The damage done by first and second

Table 1. Control of Worms — July 12 - 13

Insecticide	Concentration %	Numbers of surviving worms per 10 plants. Replicate A	B	C	Treatment total	Control %
DDT	5	1	1	1	3	95.6
	5/3	3	4	3	10	85.2
	5/9	8	3	4	15	77.8
Toxaphene	1	17	6	12	35	48.3
	1/3	16	14	11	41	39.4
	1/9	15	17	10	42	38.0
Dilan	1	0	1	0	1	98.5
	1/3	1	1	0	2	97.0
	1/9	2	3	2	7	89.7
Dieldrin	1	11	6	2	19	71.9
	1/3	13	10	12	35	48.3
	1/9	12	8	14	34	49.8
Isodrin	1	5	9	7	21	69.0
	1/3	14	7	17	38	43.9
	1/9	12	14	13	39	42.4
Endrin	1	1	0	0	1	98.5
	1/9	13	7	13	33	51.3
Control	..	21	18	16	55	Mean = 67.7
	..	24	12	23	59	
	..	24	22	43	89	

Table 1a. Control of Damage

Insecticide	July 12th - 13th Score per replicate A	B	C	Treatment total	Control %	July 19th Score per replicate A	B	C	Treatment total	Control %
DDT	2	1	0	3	95.9	9	2	0	11	89.7
	5	3	0	8	89.0	10	7	0	17	84.0
	10	4	3	17	76.7	22	11	6	39	63.3
Toxaphene	7	4	9	21	71.2	13	8	18	39	63.3
	19	14	10	43	41.1	19	24	14	57	46.4
	19	20	10	49	32.9	33	32	14	79	25.7
Dilan	0	1	0	1	98.6	2	4	3	9	91.5
	4	3	1	8	89.0	5	7	6	18	83.1
	8	3	7	18	75.3	12	9	7	28	73.7
Dieldrin	4	3	1	8	89.0	7	5	0	12	88.7
	8	5	8	21	71.2	9	14	18	41	61.4
	15	15	16	46	37.0	17	24	17	58	45.4
Isodrin	1	3	1	5	93.2	6	4	2	12	88.7
	7	3	7	17	76.7	9	13	18	40	62.4
	18	15	8	41	43.8	15	21	14	50	53.0
Endrin	0	0	0	0	100.0	3	2	1	6	94.4
	1	2	2	5	93.2	10	2	10	22	79.3
Control	26	25	19	70	Mean = 73.0	35	32	31	98	Mean = 106.3
	28	26	21	75		41	35	37	113	
	23	24	27	74		28	34	46	108	

TABLE 2. STAGES OF IMPORTED CABBAGE WORMS PRESENT ON JULY 12 AND 13

Insecticide	Concentration %	No. of eggs per 30 plants	Number of larvae and pupae per 30 plants					
			Instar					
			1st	2nd	3rd	4th	5th	Pupae
DDT	5	1	1	0	2	0	0	0
	5/3	3	2	4	1	1	0	2
	5/9	1	0	8	3	0	0	4
Toxaphene	1	4	3	8	15	4	4	1
	1/3	12	1	6	10	7	12	5
	1/9	4	0	6	16	8	10	2
Dilan	1	6	1	0	0	0	0	0
	1/3	3	0	0	0	0	1	1
	1/9	5	0	4	0	0	0	3
Dieldrin	1	5	0	9	4	4	1	1
	1/3	3	3	5	9	11	4	3
	1/9	1	0	4	7	11	9	3
Isodrin	1	3	1	8	9	3	0	0
	1/3	6	1	13	17	6	0	1
	1/9	3	1	7	16	7	5	3
Endrin	1	11	1	0	0	0	0	0
	1/9	6	6	9	15	2	0	1
Control	..	7	2	9	6	7	18	3
	..	6	3	9	15	8	17	7
	..	8	1	10	22	22	24	3

instar larvae was confined almost entirely to the outer leaves (see below) and was very slight compared with the ravages of the larger individuals in the centers of the plants. The toxaphene proved unsatisfactory and extrapolation indicates that even the usual 10 per cent dust would not have given an adequate control. It is worth noting that, in a test against the imported cabbage worm in Wisconsin, the control given by 1 lb. toxaphene per acre applied as a wettable powder spray suspension, if considered as a 3 per cent dust applied at 33 lbs. per acre, agrees well with the figures obtained in the present experiment. The point "W" in Figure 3 refers to this observation. Although Dilan gave good control of the imported cabbage worm, the material tended to induce heavy infestations of the cabbage aphid (*Brevicoryne brassicae* L.).

A comparison of the data on control of damage taken one and two weeks after treatment (Table 1) shows that only the endrin 1 per cent dust remained effective at the end of the experiment.

There is a certain lack of agreement between the degree of control obtained as shown by counts of surviving larvae and by estimates of damage made on an index basis. An insecticide which acts slowly may allow the larvae to reach third instar before succumbing to the poison; a minor amount of damage would then occur even though several larvae would be present. Another insecticide may act rapidly but fail to give a complete kill of larvae; small numbers of surviving individuals may then persist until mature and do severe damage. Unless an allowance

is made for the stages of larvae present, counts of total surviving larvae would underestimate the effectiveness of the insecticide in the first case but would overestimate its effectiveness in the second case. From the viewpoint of degree of economic control obtained, a suitably chosen and standardized damage index scale would seem to be preferable for estimating the relative efficiencies of several insecticides. This discrepancy between the two methods is demonstrated by the figures given in Table 1 for toxaphene, dieldrin and isodrin. Thus, isodrin is rather inferior to dieldrin on the basis of counts of surviving larvae, but slightly superior when the control of damage is considered as the criterion of efficiency. The large number of young second and third instar larvae (Table 2) found on the toxaphene treated plants also tended to exaggerate the inefficiency of this material.

DDT Resistance in the Imported Cabbage Worm

In 1952, McEwen and Chapman (6) reported the existence of an imported cabbage worm population which had become highly resistant to DDT. They showed by a series of laboratory and field experiments that the resistant population was not widespread but confined to an area some 6 to 8 miles in radius in Kenosha and Racine counties in Wisconsin. Evidence of increased resistance to DDT is also given by Hervey and Swenson (5) for an imported cabbage worm population in western New York State where the effectiveness of DDT, in tests carried out since 1944, had apparently declined. This had necessitated the use of dusts of increasingly higher concentrations in order to obtain a satisfactory control of the pest. The present investigation indicated that, in Connecticut, DDT still gave an adequate control in the area in which the test was carried out but that it was not as effective in 1954 as when first used; in 1944, a ½ per cent DDT dust gave approximately 98 per cent control (9). An examination was made within the limitations of the data reported in these experiments to see if any general observations or inferences were possible.

In Figure 4, certain of the results from the above experiments are shown plotted on a logarithmic-probability grid. In the Wisconsin experiments, the DDT was applied as a spray suspension while, in the other cases, dust formulations were used. Therefore, the data have been plotted in terms of pounds of toxicant per acre per application using only results based on counts of surviving larvae.

A detailed comparison of such data did not, at first glance, seem to be justified owing to the diverse conditions of experimentation. However, when the data were plotted as in Figure 4, it was seen that the regressions were very similar in slope which indicated that similar basic response factors may have been operating throughout. Therefore, the regression lines were fitted statistically to a common slope ($b = 1.2331$) by the method of least squares. The relative original tolerance levels of the populations of the three areas remain in doubt unless it can be assumed that, at first, all responded similarly to DDT. This assumption does not seem to be too unjustified since the behavior of the Connecticut and western New York populations appears to have

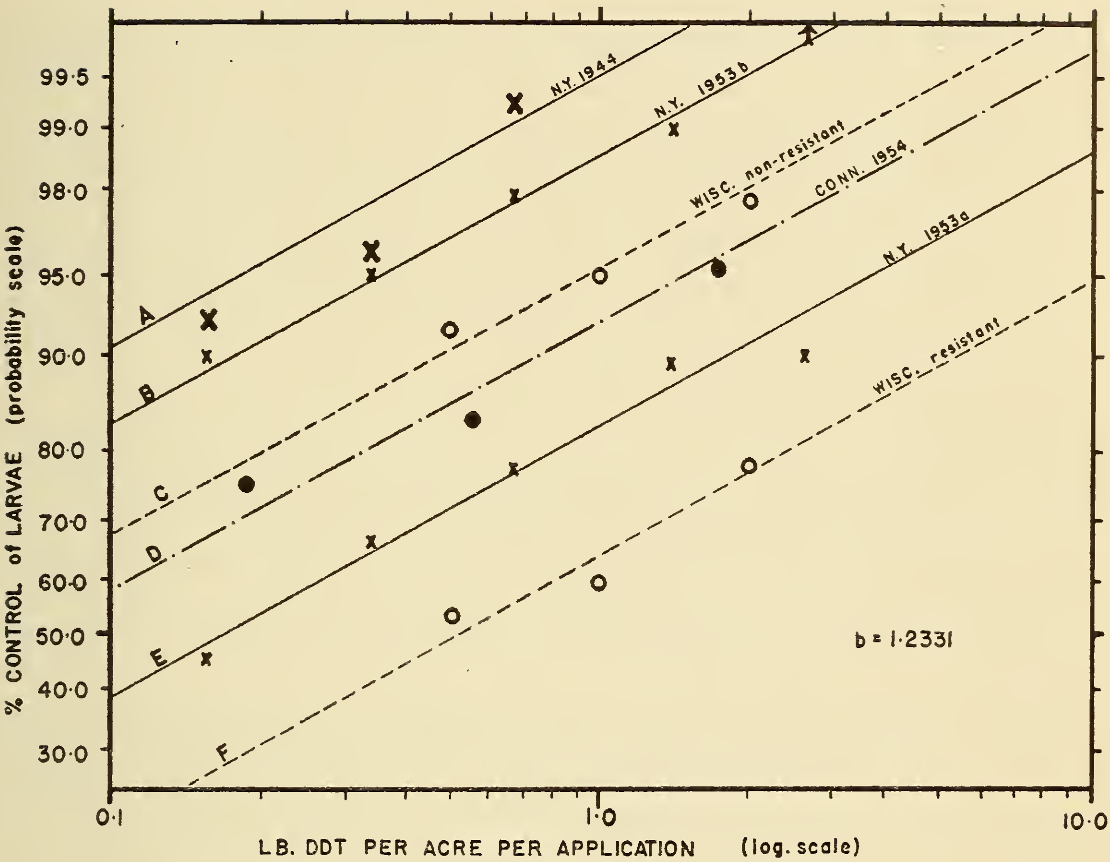

Figure 4. The variation in performance of DDT against the imported cabbage worm in Wisconsin, western New York State, and Connecticut.

been similar in 1944 (5), (9). Also, the response of the pest to toxaphene in both Connecticut and Wisconsin was similar. The influence of formulation on the relative positions of the curves for the Wisconsin and the remaining data is also doubtful. The effect of different degrees of coverage during treatment would be expected to be reflected in the slopes of the regression lines but should not have seriously affected their relative positions.

Hervey and Swenson (5) consider their 1944 and 1953a data to be directly comparable. This being so, then curves A and E indicate an approximately 22-fold increase in resistance to DDT during the intervening years, even though an adequate control was still obtained in the 1953a test. Their 1953b results (curve B), however, show only a two-fold increase but it is not clear to what extent the increased number of applications given in this case would have influenced the situation. Also, the experiments were carried out in different localities (some 10 miles apart [4]) which may also account in part for the discrepancy (6). It is apparent that varying degrees of resistance are now present in imported cabbage worm populations in northwestern New York State.

In Wisconsin, the "non-resistant" and "resistant" populations (curves C and F respectively) differ in susceptibilities by a ratio of approximately 1:12 yet DDT did not give an adequate control of the more resistant

population. By comparison with the situation in New York State it is inferred that the over-all tolerance of both of the Wisconsin populations was probably greater. If the *original* tolerance level of the Wisconsin populations had been similar to those of western New York State, the "resistant" Wisconsin population had acquired a 65-fold increase in tolerance by 1951. This would be more in keeping with the poor control of the pest by DDT in the reported experiments. In brief, if a 22-fold increase in resistance in western New York State just permitted of an adequate though inferior degree of control, a 65-fold increase in resistance would be expected to give a worse and inadequate control, as recorded in Wisconsin.

Curve D represents the Connecticut data obtained in the experiment described above. A ten-fold increase in tolerance since the advent of DDT was indicated by a comparison with curve A (5) and from previous knowledge of the performance of DDT dusts in the locality (9). In certain localized areas, it is probable that resistance greater than that demonstrated in the experiment may be present. Further experiments in other localities will be necessary to establish completely the *status quo* in Connecticut.

The localized nature of the foci of hyper-tolerant populations (6) makes it difficult to extrapolate very widely the findings of any one experiment. It is only to be expected that the insect will be most highly resistant on farms where DDT has been continuously and extensively applied during the past ten years, and that the degree of tolerance will vary from site to site. By following from time to time trends in the effectiveness of a given insecticide it should be possible to say with fair certainty whether or not excessive resistance is likely to develop at all and, if so, just how long the current control measure is likely to remain successful.

At present the evidence on the subject of insect resistance to insecticides points towards the use of two or more suitable insecticides in the control program. The change in the tolerance to DDT of imported cabbage worm populations is a warning which can be followed throughout its development and which should be heeded. The resistance of insects to chemicals is not an "all or nothing" phenomenon; it is a dynamic process and all insects offer some resistance to a chemical. To use the unqualified adjective "resistant" to describe a population of insects which is no longer being economically controlled by the chemical in question is to use the term restrictively and ambiguously. An insect does not suddenly become resistant because an insecticidal control measure is unsuccessful and Figure 4 shows that wide variations in tolerance levels to DDT of imported cabbage worm populations can and do occur. A change to a pesticide other than DDT for controlling this pest is clearly indicated.

LIFE CYCLE AND HABITS OF *Pieris rapae* (L.) IN CONNECTICUT

The life cycle of *P. rapae* in Connecticut has been reported briefly by Britton and Lowry (1). Observations made during the course of the experiment described above are shown schematically in Figure 2.

The rates of development of the various stages were found to be as described previously (1), but observations on certain of the habits of the insect seemed to warrant further report.

When first laid, the eggs are pale white but gradually darken in color so that they are a bright yellow just before hatching. This can be used as a guide to recent adult activity since the presence of white eggs implies recent egg-laying. At the temperatures prevailing during the experiment, the eggs took from five to seven days to hatch and the total time for larval development was some 14 days. The pupal period lasted six to seven days.

The adult female butterflies were seen on the wing during all hours of sunlight and appear to lay eggs throughout the day when weather conditions are suitable (7). A mere two or three seconds is all the time needed for the actual laying of the egg. The adults do not appear to rest within the cabbage crop to any great extent, but prefer to migrate to and from suitable neighboring flowering plants, from which they presumably derive nourishment. Hence the outermost plants of a cabbage crop receive a heavier initial infestation than do those more centrally situated since the former plants are those first encountered by the immigrating butterflies. This factor should be taken into account in designing experiments and preferably four to six guard rows should be left around the experimental area.

The female butterfly appears to avoid egg-laying on unhealthy or distorted plants; it does not seem to matter whether these abnormalities are due to genetic or to pestilent factors. For instance, no eggs were ever found on a "kohlrabi type" plant occurring in one of the guard rows although surrounding plants were all heavily attacked. Similarly, a plant severely infested with the cabbage aphis (*Brevicoryne brassicae* L.) was also free of *P. rapae* larvae. Observations made towards the end of the experiment indicated that the female butterflies were not egg-laying on plants already devastated by the caterpillars. Thus, badly attacked control and guard row plants were free of eggs while undamaged plants on plots which had received insecticidal treatment earlier in the experiment were rapidly becoming infested when the effects of the treatments had worn off. Very few eggs were found on DDT-treated plants but the figures obtained, which are given in Table 2, are too scanty to permit of a definite conclusion as to whether DDT did, in fact, deter the females from egg-laying.

The female butterfly lays the eggs mainly on the under surfaces of the healthy outer leaves of the cabbage plant. Eggs were found less frequently on the lighter colored wrapping leaves in the center of the plant and none were found in the heart itself. There appeared to be very little discrimination in egg-laying by the female between the upper and lower leaf surfaces of the wrapping leaves. Such leaves are but lightly waxed and the texture of both surfaces is similar.

As might be expected from the egg-laying habits, newly hatched larvae were mainly found on the under surface of the outer leaves. The caterpillars did not seem to migrate towards the heart of the plant

until the third instar was reached so that only the larger worms were found therein. Young larvae in secluded niches where they may escape initial contact with the insecticide may acquire a lethal dose while migrating towards the center of the plant. This habit could materially affect the degree of control obtained from chemical treatments.

SUMMARY

The use of an alternation or rotation of insecticides, or of "combinations" or pairs of insecticides are considered as possible methods for combating the development of acquired resistance to insecticides by the imported cabbage worm, *Pieris rapae* (L.).

A description is given of a compressed air operated hand duster which can be used to apply small quantities of dust to experimental plots.

The relative efficiencies of DDT, toxaphene, Dilan, dieldrin, isodrin and endrin dusts for control of the imported cabbage worm were assessed in a field experiment carried out in Connecticut. Endrin and Dilan were very potent, DDT still gave an adequate control, but dieldrin, isodrin and toxaphene were not considered to be very effective. Dilan appears to induce cabbage aphis infestation.

Counts of worms surviving the treatment may give a false impression of the efficiency of a given chemical in preventing damage. The use of damage index assessments as a supplement would prevent this occurring. Alternatively a suitable correction for the stages of the larvae present should be made and applied accordingly.

There is evidence that the imported cabbage worm is appreciably tolerant to DDT in Connecticut and that an alternative material should be used to control the pest.

A comparison is made of the degrees of resistance to DDT of populations of the pest in Wisconsin, western New York State and in Connecticut. Imported cabbage worm populations appear to show a wide range of tolerance to DDT.

A number of observations on the life cycle and habits of the pest in Connecticut are recorded. Eggs do not appear to be laid on unhealthy or distorted plants. They are mainly placed on the under surface of healthy outer leaves where the larvae remain and feed until reaching third instar. At this stage they appear to migrate towards the center of the plant. This migrational habit could affect the performance of an insecticide.

The rate of development of the imported cabbage worm in Connecticut was found to be as reported by previous workers.

ACKNOWLEDGMENTS

The writer would like to express his appreciation of the generosity of the W. K. Kellogg Foundation in providing the Fellowship which covered personal maintenance expenses during the period in which the work was carried out. The Director and Board of Control of The Connecticut Agricultural Experiment Station very kindly provided the laboratory and field facilities and allowed the work to be published as an Experiment Station Bulletin. For guidance throughout the course of the work the writer would like to thank Mr. Neely Turner, Chief Entomologist. Dr. James B. Kring gave invaluable help at the outset of the work, and Mr. A. De Caprio, Mrs. Joan Curtiss and Miss Nancy Anderson kindly assisted in carrying out the field operations.

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